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Characterization of a scintillating fibers read by MPPC detectors trigger prototype for the AMADEUS experiment

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ABSTRACT: Multi-Pixel Photon Counters (MPPC) consist of hundreds of micro silicon Avalanche PhotoDiodes (APD) working in Geiger mode. The high gain and the low noise, typical of these devices, together with their good performance in magnetic field, make them ideal readout detectors for scintillating fibers as trigger detectors in particle and nuclear physics experiments like AMADEUS, where such detectors are planned to be used to trigger on charged kaon pairs. In order to investigate the detection efficiency of such a system, a prototype setup consisting of 32, 1 mm diameter scintillating fibers, arranged in two double layers of 16 fibers each, and read out by 64 MPPCs with an ad-hoc built readout electronics, was tested at the πM-1 line of the Paul Scherrer Institute (PSI) in Villigen, Switzerland. The detection efficiency and the trigger capability were measured on a beam containing protons, electrons, muons and pions with a momentum of 440 MeV/c. The measured average efficiency for protons for a double layer of scintillating fibers ($96.9 \pm 1.2\%$) represents a guarantee of the good performance of this system as a trigger for the AMADEUS experiment.

KEYWORDS: Photon detectors for UV, visible and IR photons; Scintillators, scintillation and light emission processes; Trigger detectors.

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1. Introduction

The AMADEUS experiment [1, 2] aims to perform low-energy charged kaons interactions in nuclear matter measurements, in particular to search for the so-called "kaonic nuclear clusters". The AMADEUS setup is going to be installed inside the KLOE detector [3] in the free space inside the drift chamber [4]. The experiment will then use the drift chamber and the calorimeter of the KLOE detector, together with a dedicated setup consisting of a target cell to be filled with deuterium, ^3He or ^4He, and a dedicated trigger system, which will trigger on the back-to-back K^+K^- pairs emitted from the decays of the Φ particles produced at the DAΦNE e^+e^- collider of LNF-INFN [5]. For what concerns the trigger system, there are a series of constraints which have to be fulfilled:

- *Reduced dimensions:* the system has to be small and compact, in order to fit inside the 50 cm diameter space inside the KLOE drift chamber.
- *Good performance in magnetic field:* the system has to work inside a 0.6 T magnetic field.
- *Work at room temperature:* the possibilities to install a cryogenic system inside the KLOE drift chamber are very limited, so the trigger detectors have to work at room temperature.
- *Detection efficiency:* a high detection efficiency of the system is fundamental in order not to lose good events.
- *Good timing resolution:* in order to distinguish the slow kaons from background particles coming from beam losses by time of flight (TOF), a timing resolution of $\sim 300\,ps\,(\sigma)$ is needed.

- *Trigger capability:* in addition to the timing information, the possibility to distiguish the kaons from charged MIPs by energy loss, enhances the performance of the system.

Small dimensions and the possibility to be operated in a strong magnetic fields are intrinsic properties of the Multixel Photon Counter detectors (MPPC) [6, 7, 8, 9]; these detectors can be easily coupled to plastic scintillating fibers, being used for the final readout of the photons created by the energy deposited by the kaons. Measurements of the time resolution and of the capacity to work at room temperature have been already performed and the results, fulfilling the above constraints, are published [10]. In this work, the trigger capability and the detection efficiency are investigated by using the πM-1 beam at the PSI.

2. The trigger prototype setup

2.1 Detectors and fibers selection

In the AMADEUS experiment, the scintillating fibers will be arranged in a cylindrical double layer structure surrounding the DAΦNE beam pipe (see fig.1, left), in order to increase the detection (geometrical) efficiency. The prototype setup built for the system characterization consists of two separable metallic rings hosting 32 scintillating fibers read by 64 MPPCs. Each ring contains two double layers of 16 fibers each (8+8), reproducing the AMADEUS geometry. Each double layer is wrapped with black tape, in order to be light tight. A picture of the setup is shown in fig. 1 (right).

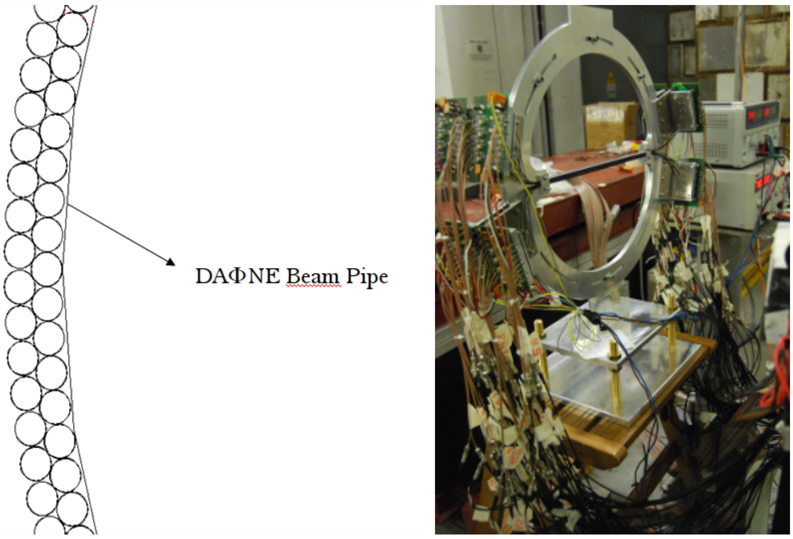

Figure 1. The double layer structure in the AMADEUS experiment cross-view (left) and the 64 channels prototype consisting in two rings, each of them formed by a double layer of 16 fibers each (right).

The choice of the MPPC device type was done taking into account a series of parameters, as the number of pixels, the fill factor, the peak sensitivity wavelength (400 nm in our case), the photon detection efficiency, the dark current rate and the gain. After having performed tests on MPPC devices from different producers, we checked that those better matching our requirements are the HAMAMATSU S10362-11-050U ones, equipped with metallic package. These devices

have 1 mm^2 active area, 400 pixels 50x50 μm^2 each, and a gain factor (at room temperature) of 7.5×10^5. For the scintillating fibers, the round shaped (1mm diameter) BICRON BCF-10 ones, 50 cm long were used.

2.2 Readout electronics

Dedicated electronics modules were designed and built at LNF-INFN for the MPPC readout. MPPC signals are pre-amplified in a 8-channel board, providing a transimpedance of $1\,K\Omega$ and a $\sim$ 10 amplification factor. The analog output signals of these boards are individually processed by a constant fraction discriminators module (also developed at LNF-INFN) which provides 64 ECL outputs and 5 NIM signals corresponding to the logic OR of the 64 channels. Performances of the preamplifiers and the time resolution obtained with this electronics have been checked in laboratory tests, using the light of a blue laser [10]. Pictures of the constant fraction discriminators box and of a single 8 channel preamplifier board are shown in fig. 2

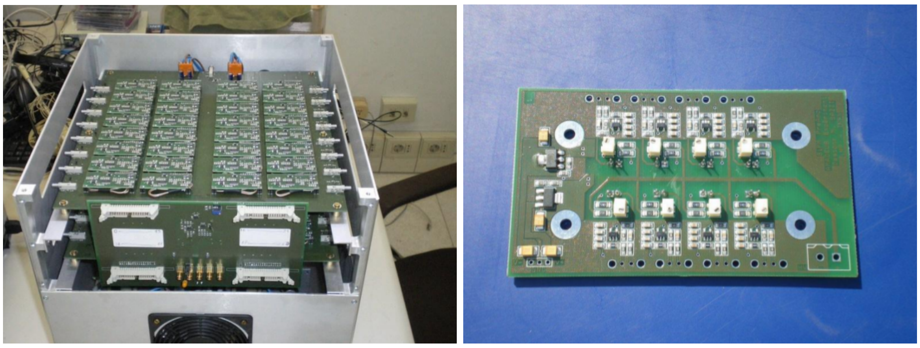

Figure 2. Constant fraction discriminators box (left) and the 8 channels pre-amplifier board (right).

2.3 πM-1 beam settings

The efficiency measurements were performed on the πM-1 line at the Paul Scherrer Institute (PSI) in Villigen [11]; the beam can be tuned in order to have protons, with momenta in the range between 350 and 500 MeV/c, with a small contamination of MIPs (π, e^-, μ). This configuration allows to test the characteristics of our setup in AMADEUS-like conditions. According to MC simulations, the energy loss in the 1mm thick scintillating fibers by the kaons coming from DAΦNE is comparable to the energy loss by 240 MeV/c momentum protons. However, to reduce the MIPs contamination, the πM-1 proton beam was set to a momentum of 440 MeV/c; in this configuration, a residual MIPs contamination $\sim 6\%$ was present. In tab. 1 results of the simulations for energy loss in 1mm scintillating fibers are shown.

The energy loss signal from 440 MeV/c momentum protons is a factor ~ 2.5 lower than the one expected in DAΦNE, which makes the conditions from PSI even more restrictive. In addition to this trigger prototype, 3 small scintillators were used for triggering the acquisition and for particle identification. The scheme of the overall test setup (not in scale) as installed on the $\pi M-1$ beam line is shown in fig. 3. Scintillators 1 and 2 are $15\,cm \times 1.2\,cm, 1\,cm$ thickness, while scintillator 3 is $15\,cm \times 2\,cm, 1\,cm$ thickness; the crossing surface of scintillators 2 and 3 (DAQ trigger in coincidence with the πM-1 RadioFrequency clock) is then $2 \times 1.2\,cm^2$. In fig. 3 the arrow is

Particles	Momentum (MeV/c)	Energy loss in 1 mm (MeV)
K^-	127	1.94
p	240	1.92
p	440	0.76

Table 1. Energy loss in 1 mm thick scintillating fibers by DAΦNE kaons, 240 MeV/c and 440 MeV/c πM-1 protons calculated with a MC simulations (GEANT3).

the proton beam; trigger is given by scintillators 2 and 3, crossing at 90 degrees. Fibers layers are numbered from L1 to L4 while the fibers in each layer from 1 to 8. Using remote controlled adjustable slits, the beam was operated in single particle mode with a frequency of 50 MHz and a spot size of few centimeters [11].

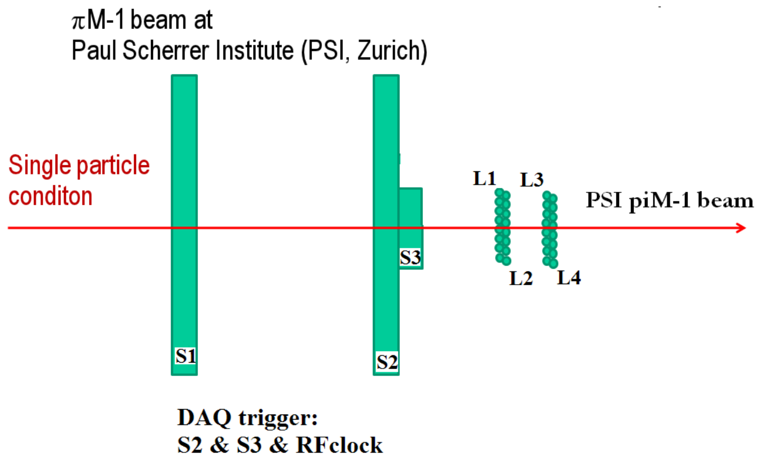

Figure 3. Overall scheme of the setup with the 3 scintillators and the two double layers scintillating fibers system (not in scale).

3. Experimental results

The data from the 32 fibers and from the 3 scintillators were acquired with a VME DAQ chain, using two 32 channels QDCs (CAEN V792) and one 16 channel QDC (CAEN V792n) for the charge information, two 32 channels TDCs (CAEN V1190B) and one 16 channel TDC (CAEN V1190A) for the timing information, and a 32 channels ADC (CAEN V785) storing the temperature of the setup via a PT100 sensor. The thresholds on the costant fractions were set to give an OR dark count rate of few Hz. The analyzed data correspond to a 690 minutes continuous run, performed in June 2012.

3.1 Events selection

In the analysis procedure, the temperature stability ($\simeq$ 31 Celsius) was checked using a PT-100 sensor directly attached to the metallic hosting of the MPPCs. Protons and MIPs are identified using the energy deposition correlation plot between S1 and S2, as shown in fig. 4. The acquired

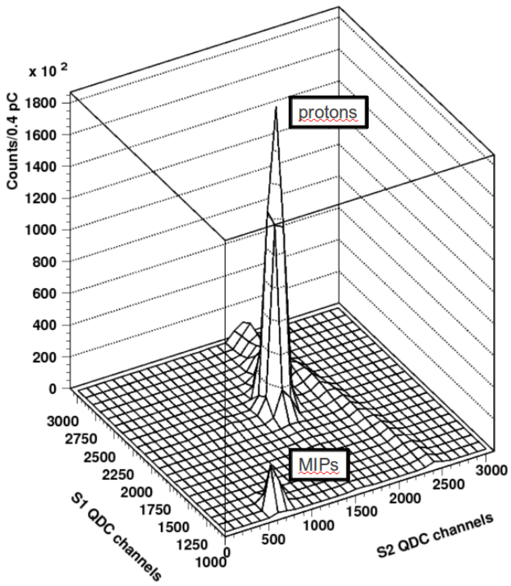

Figure 4. 3D plots of S1 and S2 QDCs; protons and MIPs peaks are identified and labeled.

events are mainly protons with a few percentage contribution of MIPs. A very important check relates to the protons multiplicity: working in single particle configuration is fundamental for a correct efficiency measurement, thus only events in which, for each layer, only one fiber is fired are kept for the efficiency determination. In fig. 5, the total number of events in which 1, 2, 3 or 4 layers are fired when single hit per layer is requested (up) and when at least one layer has a double hit (down). The measurement shows that $\sim 93\%$ of the events are single particle events; rejecting events corresponding to the lower plot, also the cross talk between fibers of the same layer is avoided.

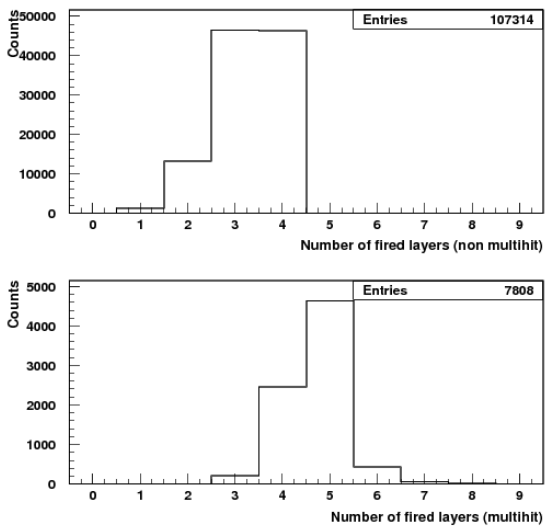

Figure 5. Single particle condition check; number of events in which 1, 2, 3, or 4 layers are fired when single hit per layer is request (up), and when at least one layer has a multihit (down).

3.2 Detection efficiency

The detection efficiency of the double layer system measurement was performed using S1, S2 and L4 as reference. A good event is defined as an event in which a proton or a MIP, tagged by the two scintillators, gives a hit on one fiber of the layer 4 (NHITS4=1). The detection efficiency of the double layer (layer 1 + layer 2) is then defined as:

$$Eff_{1+2} = \frac{Entr(1 \leq NHITS1 + NHITS2 \leq 2)}{Entr(NHITS4 = 1)} \tag{3.1}$$

where NHITS1, NHITS2 and NHITS4 are the number of hits on layer 1, 2 and 4 and Entr(A) means the number of events fulfilling the condition A. Histograms of this measurement are shown in fig. 6.

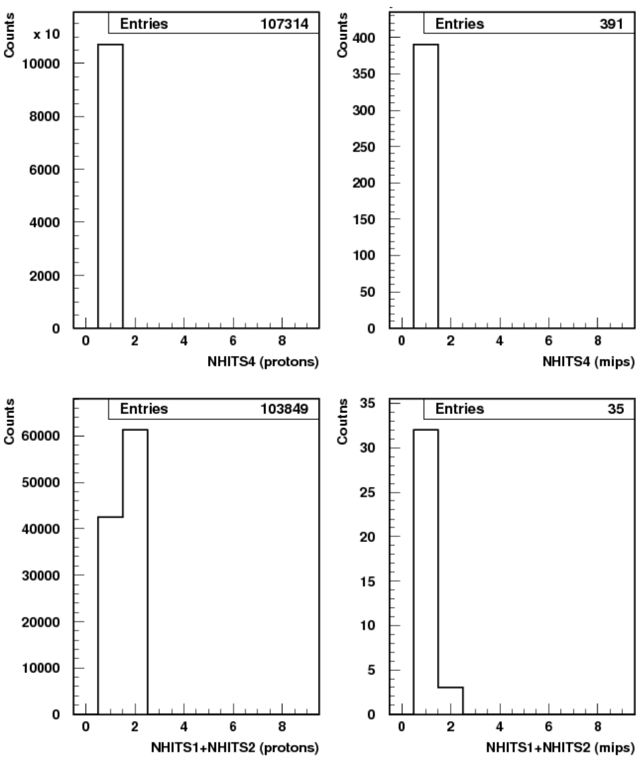

Figure 6. Total number of events with NHITS4=1 (up) and the ones detected by the double layer L1+L2 (down), for protons (left) and MIPs (right).

The measured efficiency for protons is:

$$Eff_{1+2}^{prot} = (96.8 \pm 0.4(stat))\% \tag{3.2}$$

For what concerns the MIPs, the measured value of $Eff_{1+2}^{MIPs} = (8.9 \pm 1.5(stat))\%$ implies a rejection factor of more than 90%. For a complete characterization of the prototype, very important information can be obtained from the charge deposition; as an example, the QDC plot of the left and right MPPCs reading the fiber 5 of L1 are shown in fig. 7, for protons (black) and MIPs (red).

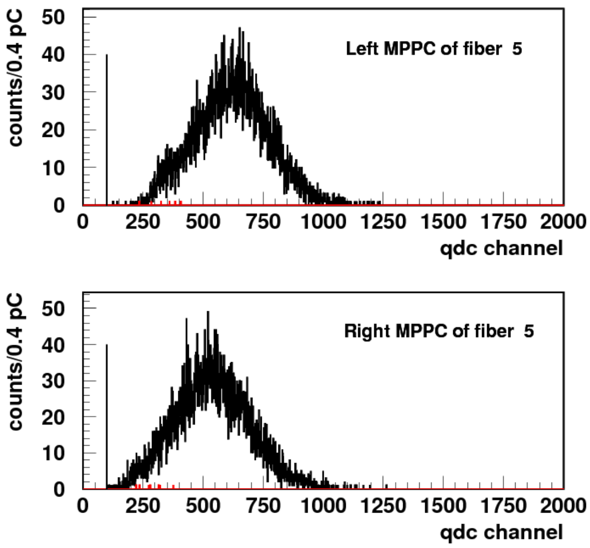

Figure 7. QDC plots of the two MPPCs reading the fiber number 5 of the L1; protons (black) and MIPs (red) events are shown. The vertical line represents the hardware threshold on constant fraction discriminators ($\simeq$ 10 photons).

These measurements show how, setting a hardware threshold on the discriminators corresponding to $\simeq$ 10 photons signals, more than 90% of the MIPs are not detected by the prototype setup, optimizing the efficiency of the the trigger system in detecting charged kaons and rejecting MIPs.
The same analysis has been done selecting each fiber, instead of the whole L4, as trigger for good events; results of this position scan of the detection efficiencies of (L1+L2) are shown in tab. 2. Due to the poor statistics of the MIPs events, this scan could only be done for the protons.

Triggering fiber in L4	Efficiency of (L1+L2) (%)
1	91.1 ± 1.3
2	98.3 ± 1.3
3	97.2 ± 1.3
4	97.5 ± 1.3
5	99.1 ± 1.1
6	99.6 ± 1.6
7	98.8 ± 1.0
8	93.2 ± 1.0

Table 2. Position scan of the detection efficieny. Each fiber is individually used as trigger for good events and the corresponding events on the double layer are counted.

The detection efficiencies for each fibers are compatible whithin each other, except for the two external ones (1 and 8); this small difference is due to edge effects of the fibers layer.

4. Conclusions

The detection efficiency and the trigger capability of a prototype system consisting of a double layer of scintillating fibers read by MPPCs have been investigated at the πM-1 beam at PSI. The detection efficiency for protons was measured to be $Eff_{1+2}^{prot} = (96.8 \pm 0.4)\%$ while the capacity to reject MIPs by their energy release in the 1 mm fibers has been measured to be $Rej_{1+2}^{MIPs} = (91.1 \pm 1.5)\%$. Based as well on the small dimensions, good behaviour in magnetic field, capability to work at room temperature and a good timing resolution, this prototype proved to be ideal as a trigger system of the AMADEUS experiment at DAΦNE, fulfilling all the requirements. More generally, this system is a very performant charged particles trigger for other possible experiments, especially those in which a magnetic fields is present.

Acknowledgments

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